Rhea Scatterometry Rev 127

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- Sequence: s58

- Rev: 127

- Observation Id: rh_127_1

- Target Body: Rhea

1 Introduction

This memo describes one of the Cassini RADAR activities for the s58 sequence of the Saturn Tour. A sequence design memo provides the science context of the scheduled observations, an overview of the pointing design, and guidelines for preparing the RADAR IEB. A 3-hour warmup occurs first using the parameters shown in table 4.

2 CIMS and Division Summary

CIMS ID	Start	End	Duration	Comments
127OT_WARMUP4RH001_RIDER	2010-061T09:50:00	2010-061T13:15:36	03:25:36.0	Warmup for scatterometry and simultaneous radiometry of icy satellite.
127RH_SCATTRAD001_PRIME	2010-061T13:15:36	2010-061T16:55:36	03:40:0.0	Point -Z axis at target and execute raster scan(s) centered on target. Obtain simultaneous scatterometry and radiometry.

Table 1: rh_127_1 CIMS Request Sequence

Each RADAR observation is represented to the project by a set of requests in the Cassini Information Management System (CIMS). The CIMS database contains requests for pointing control, time, and data volume. The CIMS requests show a high-level view of the sequence design.

The CIMS requests form the basis of a pointing design built using the project pointing design tool (PDT). The details of the pointing design are shown by the PDT plots on the corresponding tour sequence web page. (See

Division	Name	Start	Duration	Data Vol	Comments
a	distant_warmup	-7:55:0.0	05:47:0.0	20.7	Warmup
b	distant_scatterometer	-2:08:0.0	00:05:0.0	54.0	Scatterometer target-center (Rhea) with tone
c	distant_scatterometer	-2:03:0.0	00:05:0.0	54.0	Scatterometer target-center (Rhea) with chirp
d	scat_compressed	-1:58:0.0	00:10:0.0	4.2	Scatterometer rcv only off to on-Rhea 9 dB cal
e	scatterometer_imaging	-1:48:0.0	00:04:0.0	16.8	Scatterometer imaging
f	scatterometer_imaging	-1:44:0.0	00:00:12.0	0.8	Scatterometer imaging
g	scatterometer_imaging	-1:43:48.0	00:00:8.4	0.6	Scatterometer imaging
h	scatterometer_imaging	-1:43:39.6	00:00:15.6	1.1	Scatterometer imaging
i	scatterometer_imaging	-1:43:24.0	00:00:12.0	0.8	Scatterometer imaging
j	scatterometer_imaging	-1:43:12.0	00:02:30.0	10.5	Scatterometer imaging
k	scatterometer_imaging	-1:40:42.0	00:07:54.0	33.2	Scatterometer imaging
l	scatterometer_imaging	-1:32:48.0	00:00:21.0	1.5	Scatterometer imaging
m	scatterometer_imaging	-1:32:27.0	00:00:6.0	0.4	Scatterometer imaging
n	scatterometer_imaging	-1:32:21.0	00:00:9.0	0.6	Scatterometer imaging
o	scatterometer_imaging	-1:32:12.0	00:00:12.0	0.8	Scatterometer imaging
p	scatterometer_imaging	-1:32:0.0	00:00:20.4	1.4	Scatterometer imaging
q	scatterometer_imaging	-1:31:39.6	00:00:16.2	1.1	Scatterometer imaging
r	scatterometer_imaging	-1:31:23.4	00:00:39.6	2.8	Scatterometer imaging
s	scatterometer_imaging	-1:30:43.8	00:00:13.8	1.0	Scatterometer imaging
t	scatterometer_imaging	-1:30:30.0	00:00:48.0	3.4	Scatterometer imaging
u	scatterometer_imaging	-1:29:42.0	00:06:30.0	27.3	Scatterometer imaging
v	scatterometer_imaging	-1:23:12.0	00:00:54.0	7.6	Scatterometer imaging
w	scatterometer_imaging	-1:22:18.0	00:01:34.2	13.2	Scatterometer imaging
x	scatterometer_imaging	-1:20:43.8	00:00:37.8	5.3	Scatterometer imaging
y	scatterometer_imaging	-1:20:6.0	00:01:36.0	13.4	Scatterometer imaging
z	scatterometer_imaging	-1:18:30.0	00:16:30.0	138.6	Scatterometer imaging
lbrace	scatterometer_imaging	-1:02:0.0	00:01:48.0	15.1	Scatterometer imaging
vbar	scatterometer_imaging	-1:00:12.0	00:00:30.0	4.2	Scatterometer imaging
rbrace	scatterometer_imaging	-0:59:42.0	00:11:42.0	84.2	Scatterometer imaging
Total				518.7	

Table 2: Division summary. Data volumes (Mbits) are estimated from maximum data rate and division duration.

Div	Alt (km)	Slant range (km)	B3 Size (target dia)	B3 Dop. Spread (Hz)
a	253415	off target	1.07	off target
b	65226	65226	0.28	455
c	62629	62629	0.27	438
d	60035	60035	0.26	422
e	54853	55305	0.24	390
f	52783	53050	0.23	377
g	52679	52946	0.23	376
h	52607	52843	0.23	376
i	52472	52593	0.22	375
j	52369	52424	0.22	374
k	51076	51262	0.22	366
l	46992	47227	0.20	341
m	46811	46880	0.20	340
n	46759	46810	0.20	340
o	46682	46756	0.20	340
p	46578	46745	0.20	339
q	46403	46739	0.20	338
r	46263	46605	0.20	337
s	45922	46239	0.20	335
t	45804	46029	0.20	334
u	45390	45638	0.20	332
v	42035	42301	0.18	312
w	41571	41857	0.18	309
x	40761	40900	0.18	305
y	40436	40627	0.17	303
z	39611	39836	0.17	298
lbrace	31110	31377	0.13	254
vbar	30183	30475	0.13	250
rbrace	29926	30144	0.13	249

Table 3: Division geometry summary. Values are computed at the start of each division. B3 Doppler spread is for two-way 3-dB pattern. B3 size is the one-way 3-dB beamwidth

Name	Nominal	Actual	Mismatch	Comments
mode	radiometer	radiometer	no	
start_time (min)	varies	-475.0	no	
end_time (min)	varies	-128.0	no	
time_step (s)	varies	720.0	no	Used by radiometer only modes - saves commands
bem	00100	00100	no	
baq	don't care	5	no	
csr	6	6	no	6 - Radiometer Only Mode
noise_bit_setting	don't care	4.0	no	
dutycycle	don't care	0.38	no	
prf (Hz)	don't care	1000	no	
tro	don't care	0	no	
number_of_pulses	don't care	8	no	
n_bursts_in_flight	don't care	1	no	
percent_of_BW	don't care	100.0	no	
auto_rad	on	on	no	
rip (ms)	34.0	34.0	no	
max_data_rate	0.248	0.992	yes	Kbps - set for slowest burst period
interleave_flag	off	off	no	
interleave_duration (min)	don't care	10.0	no	

Table 4: rh_127_1 Div a distant_warmup block
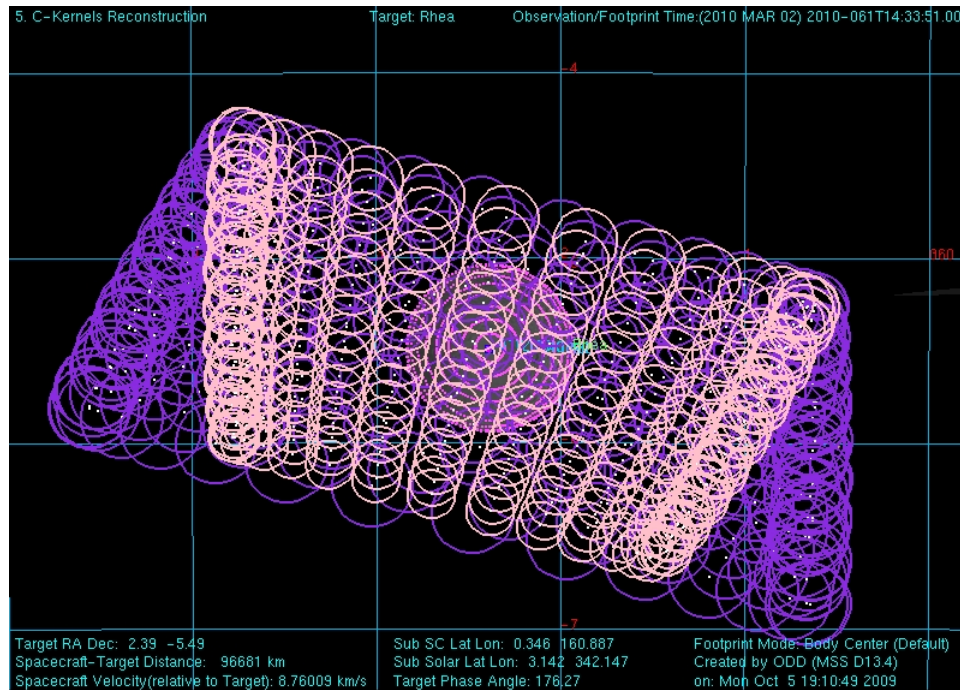
Figure 1: Div A: Radiometer raster scans

https://cassini.jpl.nasa.gov/radar.) The RADAR pointing sequence is ultimately combined with pointing sequences from other instruments to make a large merged c-kernel. C-kernels are files containing spacecraft attitude data.

A RADAR tool called RADAR Mapping and Sequencing Software (RMSS) reads the merged c-kernel along with other navigation data files, and uses these data to produce a set of instructions for the RADAR observation. The RADAR instructions are called an Instrument Execution Block (IEB). The IEB is produced by running RMSS with a radar config file that controls the process of generating IEB instructions for different segments of time. These segments of time are called divisions with a particular behavior defined by a set of division keywords in the config file. Table 2 shows a summary of the divisions used in this observation. Subsequent sections will show and discuss the keyword selections made for each division. Each division table shows a set of nominal parameters that are determined by the operating mode (eg., distant scatterometry, SAR low-res inbound). The actual division parameters from the config file are also shown, and any meaningful mismatches are flagged.

3 Overview

This observation is primarily a high altitude SAR imaging observation of Rhea. It provides the only SAR imaging data for Rhea during the entire Cassini Mission. The observation begins with the usual radiometer only warmup. Then the radar central beam is turned to Rhea for two standard inbound Radiometry raster scans at moderate range (80,000 km), followed by disk integrated tone and chirp observations just like prior distant icy satellite observations. Following these segments, the spacecraft turns the central beam off-target for calibration, and then back on-target to raster scan across the visible disk. Two complete scans are performed while the radar collects high altitude scatterometer imaging data down to an altitude of about 25,000 km.

4 Radiometry scans

Div A supplies IEB parameters for the warmup and raster-scanning radiometry. The scan layouts are shown in Fig. 1.

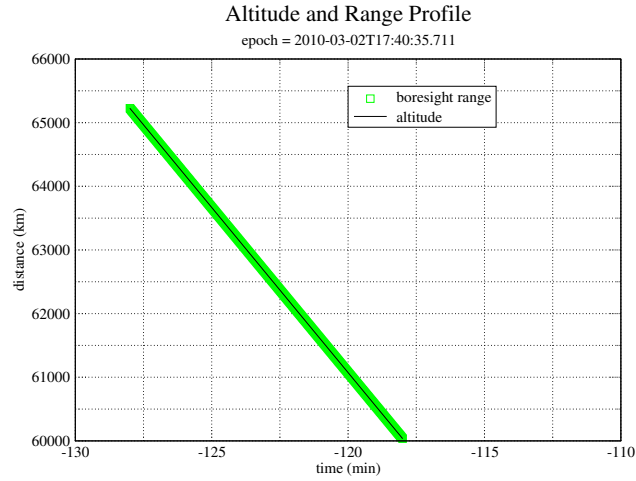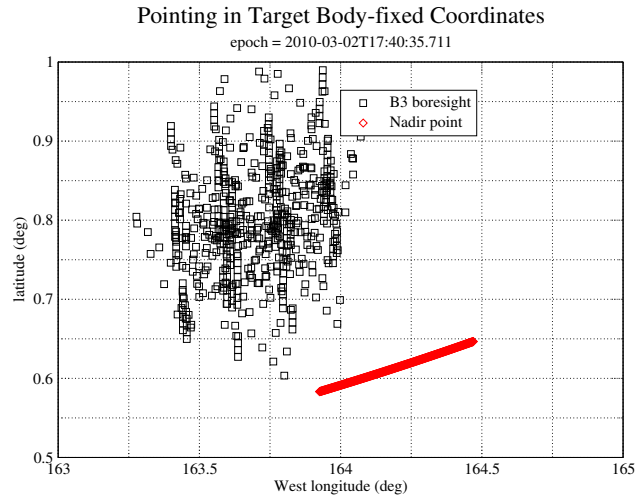Figure 2: Div B,C: Altitude and range to the boresight point

Figure 3: Div B,C: Stare in target body-fixed coordinates

5 Div's B,C: Rhea Distant Scatterometry

Figures 2 and 3 show the pointing design for the scatterometry stare from the merged ckernel. The angular size of the target is about 24.6 mrad during this division. The beam 3 beamwidth is 6 mrad. The division parameters for the tone target integration are shown in table 5, and for the chirp integration in table 6.

5.1 Distant Scatterometer Performance

The detection performance is shown in figures 4, 5, and 6. The maximum doppler spread in Div c is 438 Hz which comes from rotation and spacecraft motion. In this division, the PRF needs to be higher than the doppler spread to support potential range-doppler processing, and is set by division parameter to 1000 Hz. With this PRF, the range ambiguity spacing is 150 km while Rhea is 764 km in radius. The range-spread of the beam depends on where it is pointed. For target centered pointing the cosine law can be applied to solve the geometry. At 62629 km range, the range-spread is 25 km. These numbers show that ambiguities will not limit the usable parts of the beam in the chirp observation.

Figure 6 shows that range processing is marginal due to low SNR. The PRF is still set to 1000 Hz to cover the

Name	Nominal	Actual	Mismatch	Comments
mode	scatterometer	scatterometer	no	
start_time (min)	varies	-128.0	no	
end_time (min)	varies	-123.0	no	
time_step (s)	don't care	6.0	no	Used when BIF > 1, otherwise set by valid time calculation
bem	00100	00100	no	
baq	5	5	no	
csr	0	0	no	0 - normal operation with fixed attenuator set to match Phoebe for easier cross-calibration
noise_bit_setting	4.0	4.0	no	Scat signal set higher than ALT/SAR
dutycycle	0.70	0.70	no	
prf (Hz)	varies	822	no	Set to cover doppler spread and allow CSF*PRI = integer
tro	6	6	no	6 - allows for some noise only data in time domain
number_of_pulses	varies	56	no	depends on PRF choice (can have more shorter pulses)
n_bursts_in_flight	varies	1	no	Used to increase PRF and data rate at long range
percent_of_BW	0.0	0.0	no	
auto_rad	on	on	no	
rip (ms)	34.0	34.0	no	
max_data_rate	200.000	180.000	yes	Kbps - determines burst period
interleave_flag	off	off	no	
interleave_duration (min)	don't care	10.0	no	

Table 5: rh_127_1 Div b distant_scatterometer block

Name	Nominal	Actual	Mismatch	Comments
mode	scatterometer	scatterometer	no	
start_time (min)	varies	-123.0	no	
end_time (min)	varies	-118.0	no	
time_step (s)	don't care	6.0	no	Used when BIF > 1, otherwise set by valid time calculation
bem	00100	00100	no	
baq	5	5	no	
csr	0	0	no	0 - normal operation with fixed attenuator set to match Phoebe for easier cross-calibration
noise_bit_setting	4.0	4.0	no	Scat signal set higher than ALT/SAR
dutycycle	0.70	0.70	no	
prf (Hz)	varies	1000	no	Set to cover doppler spread
tro	6	6	no	6 - allows for some noise only data in time domain
number_of_pulses	varies	66	no	depends on PRF choice (can have more shorter pulses)
n_bursts_in_flight	varies	1	no	Used to increase PRF and data rate at long range
percent_of_BW	0.0	100.0	yes	
auto_rad	on	on	no	
rip (ms)	34.0	34.0	no	
max_data_rate	200.000	180.000	yes	Kbps - determines burst period
interleave_flag	off	off	no	
interleave_duration (min)	don't care	10.0	no	

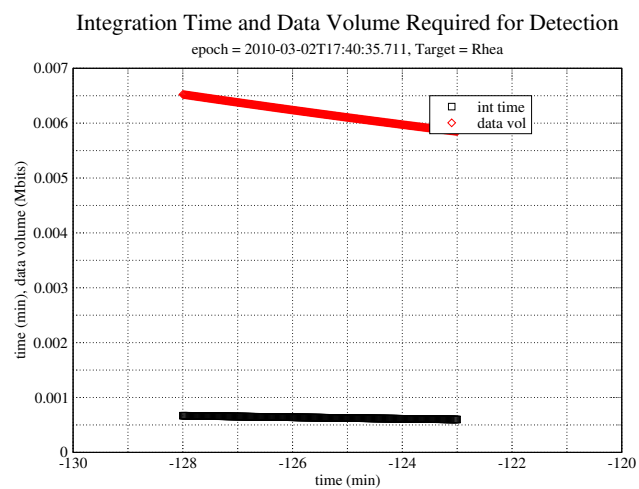Table 6: rh_127_1 Div c distant_scatterometer block

Figure 4: Scatterometry Div B: Detection integration time required for a single point detection using optimal chirp bandwidth
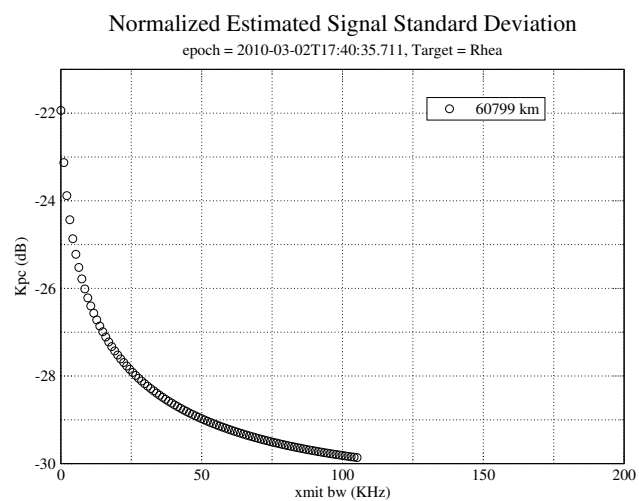

Figure 5: Div C: Normalized estimated signal standard deviation for a disk integrated observation using optimal chirp bandwidth and assuming all the bursts occur at minimum range, and 15 minutes away from minimum range.
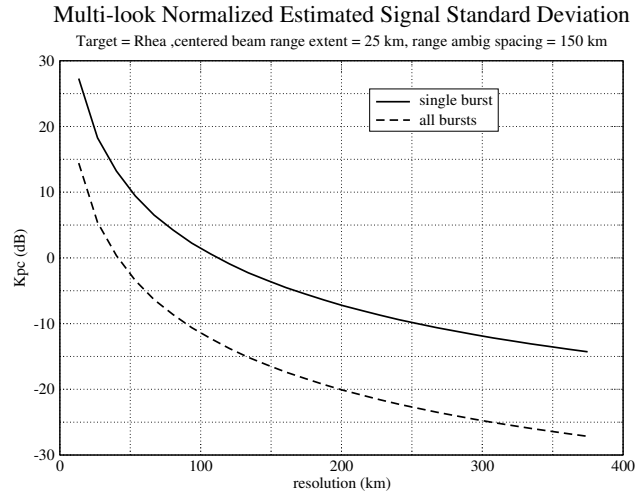
Multi-look Normalized Estimated Signal Standard Deviation

Target = Rhea ,centered beam range extent = 25 km, range ambig spacing = 150 km

Figure 6: Div C: Normalized estimated signal standard deviation for a range/doppler cell as a function of resolution. Range/doppler resolution elements are both set equal to the specified resolution. Results are shown for a single burst, and for all the bursts in this division. Calculations are performed using the geometry at the start of the division. The presence of ambiguities are not shown.

doppler spread and cleanly show the doppler spectrum. Disk integrated results from the tone division should be very stable.

6 Receive Only Calibration

Div D collects compressed receive only data in the scatterometer mode with the 9 dB attenuator setting used by the target center observations, and by the subsequent imaging collection. The data are obtained during a turn off and on-target as shown in Fig. 7. These data along with knowledge of Rhea's brightness temperature provided by the radiometry can then be processed into gain and noise temperature data for the instrument and later used to adjust calibration settings if needed. These data are collected in compressed mode to get more integration time. The PRF and number of pulses are chosen to fill the science data buffer. These parameters give the best performance possible from the compressed mode.

7 Div's E+: High Altitude Scatterometer Imaging

After the distant scatterometry, division E puts the radar into scatterometer imaging mode where it remains throughout the rest of the observation. Figs. 8 and 9 show the layout of the imaging scans which cover the entire visible disk. A typical set of parameters are shown in table 7. The following divisions vary the PRF to optimize range and doppler ambiguity ratios. Also, the second scan is given more data volume to keep up the number of looks as the beam footprint shrinks with decreasing range.

The high altitude imaging segments are designed to optimize range-doppler ambiguities, resolution, number of looks and noise-equivalent cross-section. These segments push against the 7% duty cycle limit, the 32 Kbyte size of the science data buffer, the round trip time limitation, and the number of pulses that the ESS can put out. To allow the best possible azimuth resolution, the duty cycle is reduced to allow a longer pulse train while still remaining below the 7% duty cycle limit. This trades SNR for resolution as was done in T19. Resolution in these segments will be in the 2 km range. For more technical details on range and doppler ambiguities, refer to the discussion in the T19 sequence design memo.
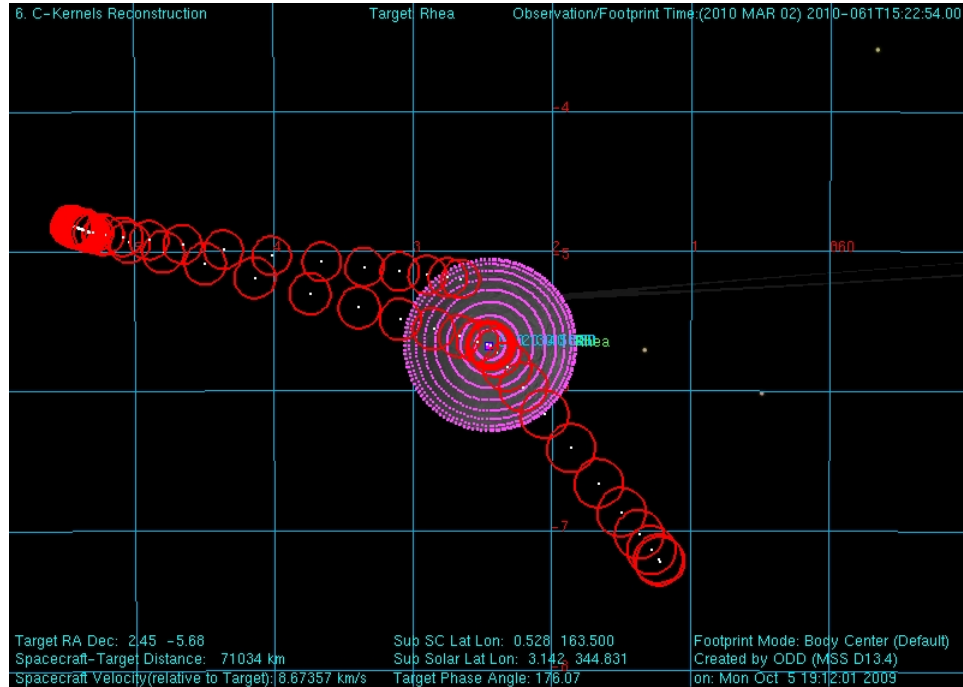
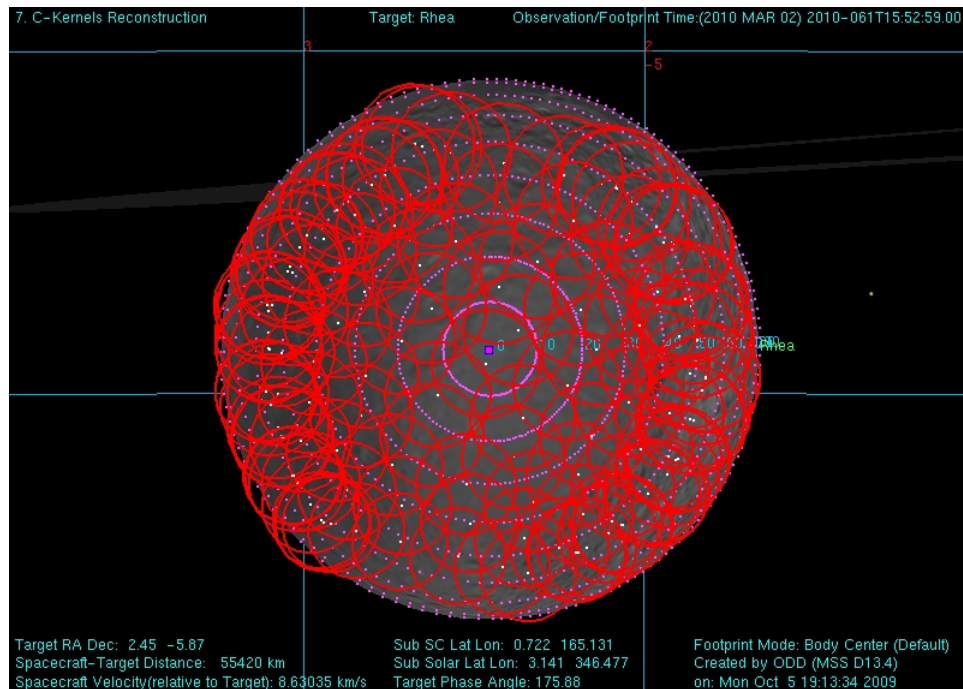Figure 7: Div D: Target Stare and off-target turn.

Figure 8: Div E+: First Beam 3 scan on Rhea for scatterometer imaging.

Name	Nominal	Actual	Mismatch	Comments
mode	scatterometer	scatterometer	no	
start_time (min)	varies	-108.0	no	
end_time (min)	varies	-104.0	no	
time_step (s)	varies	6.0	no	
bem	00100	00100	no	
baq	0	0	no	8-2 used to increase looks and duty cycle - hence SNR
csr	0	0	no	0 - fixed attenuator
noise_bit_setting	4.0	4.0	no	Noise like setting for scatt
dutycycle	0.35	0.70	yes	
prf (Hz)	1000	450	yes	1000 Hz is typical, set to balance range/doppler ambiguities
tro	6	6	no	
number_of_pulses	100	28	yes	100 is typical, set to fill echo buffer/round trip time
n_bursts_in_flight	1	1	no	
percent_of_BW	100.0	100.0	no	
auto_rad	on	on	no	
rip (ms)	34.0	34.0	no	
max_data_rate	82.000	70.000	yes	82 is typical, set to use available data volume
interleave_flag	off	off	no	
interleave_duration (min)	don't care	10.0	no	

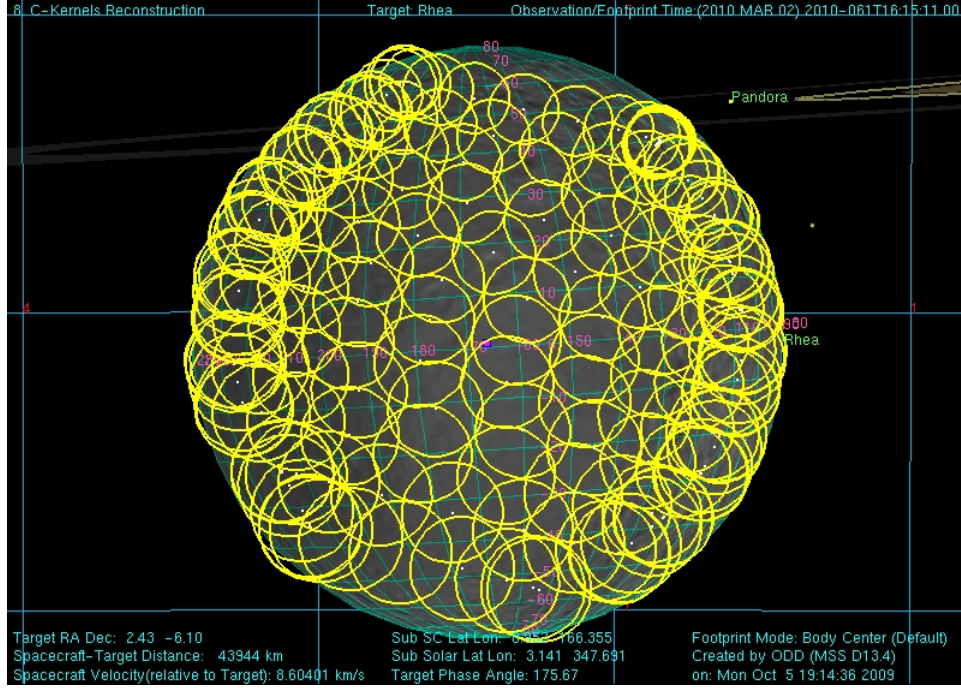Table 7: rh_127_1 Div e scatterometer_imaging block

Figure 9: Div E+: Second Beam 3 scan on Rhea for scatterometer imaging.

7.1 SAR-style Scatterometer Resolution Performance

Since SAR processing will be applied to these segments, the effective resolution can be calculated from the same equations,

$$\delta R_g = \frac{c}{2B_r \sin\theta_i}, \tag{1}$$

$$\delta x = \frac{\lambda R}{2\tau_{rw} v \sin\theta_v}, \tag{2}$$

where δR_g is the projected range resolution on the surface, c is the speed of light, B_r is the transmitted chirp bandwidth, θ_i is the incidence angle, δx is the azimuth resolution on the surface, λ is the transmitted wavelength, R is the slant range, τ_{rw} is the length of the receive window, v is the magnitude of the spacecraft velocity relative to the target body, and θ_v is the angle between the velocity vector and the look direction. Figure 10 shows the results from these equations for the scatterometer imaging time. The calculations are performed for the boresight of beam 3 which is the center of the swath.
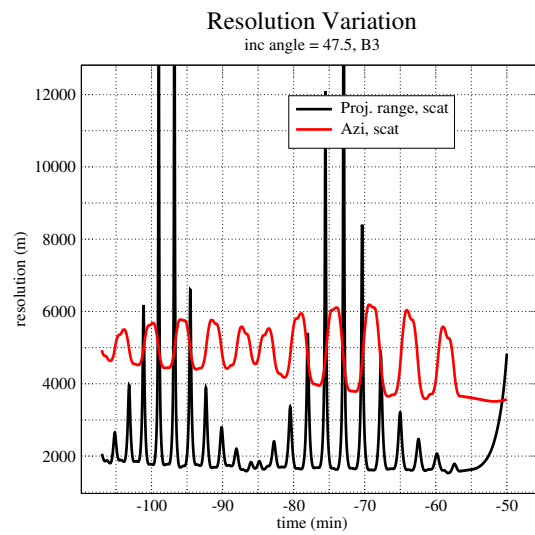
8 Revision History

1. Dec 16, 2010: Initial Release

Figure 10: Scatterometer imaging projected range and azimuth resolution. These values are estimated from predicted IEB parameters.

9 Acronym List

ALT	Altimeter - one of the radar operating modes
BAQ	Block Adaptive Quantizer
CIMS	Cassini Information Management System - a database of observations
Ckernel	NAIF kernel file containing attitude data
DLAP	Desired Look Angle Profile - spacecraft pointing profile designed for optimal SAR performance
ESS	Energy Storage System - capacitor bank used by RADAR to store transmit energy
IEB	Instrument Execution Block - instructions for the instrument
ISS	Imaging Science Subsystem
IVD	Inertial Vector Description - attitude vector data
IVP	Inertial Vector Propagator - spacecraft software, part of attitude control system
INMS	Inertial Neutral Mass Spectrometer - one of the instruments
NAIF	Navigation and Ancillary Information Facility
ORS	Optical Remote Sensing instruments
PDT	Pointing Design Tool
PRI	Pulse Repetition Interval
PRF	Pulse Repetition Frequency
RMSS	Radar Mapping Sequencing Software - produces radar IEB's
SAR	Synthetic Aperture Radar - radar imaging mode
SNR	Signal to Noise Ratio
SOP	Science Operations Plan - detailed sequence design
SOPUD	Science Operations Plan Update - phase of sequencing when SOP is updated prior to actual sequencing
SSG	SubSequence Generation - spacecraft/instrument commands are produced
SPICE	Spacecraft, Instrument, C-kernel handling software - supplied by NAIF to use NAIF kernel files.
TRO	Transmit Receive Offset - round trip delay time in units of PRI